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ABSTRACT

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The Direct Assessment of Competence for Degrees in Large Public Universities: A Multidisciplinary Approach

COMPETENCE IN THE NATURAL SCIENCES

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Abstract

This paper discusses the concept of attainment requirement and the development and assessment of attainment requirements for natural science majors. Structures involving several different kinds and levels of terminal and generic attainment are presented. The implications of such levels of attainment and performance standards for assessment strategies are discussed.

The paper also suggests ways to use similar attainment structures to delineate the material to be presented by natural science departments to non-science majors. The purpose of the paper is to discuss some issues which are related to attainment-based education and are of interest both to natural science faculty and to instructional and curriculum designers.

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Introduction

The purpose of this paper is to consider attainment-based education in the context of post-secondary education in the natural sciences. The two issues dealt with in some depth are: 1) the concepts of competence and attainment, and 2) the development and assessment of general and specific attainments for natural science majors. Two issues dealt with in less depth are: 1) the development and assessment of general and specific attainments in natural science education for majors not in the natural sciences, and 2) the description of common attainments for large groups of students.

The paper will attempt to be as free of jargon as possible. The overlap between the jargon of the educational technologist and the jargon of the natural scientist, while not zero by any means, is certainly small. When the paper deals with the science, it will try to use relatively transparent examples; most of the examples will come from physics. When the paper deals with competency-based (or other educational) concepts, it will attempt to use transparent phrases.

The Center for Educational Design and its natural science clients have dealt with many of the issues discussed in this paper. Since the paper must be kept relatively short, the reader will have to understand that the comments and suggestions made are based on experience--even when the ideas are treated somewhat fleetingly.

The natural sciences (including mathematics for the sake of this discussion) have been using forms of competency-based education for some time. Most attempts at CBE have used the Keller Plan or PSI. Although objectives are used in the Keller Plan, such attempts at CBE fall short of their potential for a number of reasons. Foremost among these reasons are the lack of a hierarchy among the instructional objectives, the lack of systematically developed assessment strategies, and the fact that most objectives identified tend to be enabling objectives rather than terminal objectives.

On the other hand, educational technology has well-developed strategies for many parts of the process of the design of instruction. However, the educational technologist is still relatively weak in areas such as the development of assessment systems, and the educational technologist often advances procedures for the various parts of instructional design which are too cumbersome and take too much effort. For example, needs analysis, while clearly of paramount importance to instructional design has often become too much of an end in itself. Other examples could include: the classification of objectives far beyond any practical importance, or the development of evaluative systems which gather so much extraneous data that it takes too much effort just to evaluate a simple instructional program.

The point of this paper is to try to take one set of issues of interest to both natural scientists and instructional designers, and try to delineate the options, difficulties, ideas, and basic concepts.

The Concepts of Competency and Attainment

The concept of competency, although much in vogue in education, is a concept inappropriate to the educational process. Competency is essentially a life-long issue and is constantly re-evaluated and assessed by co-workers, superiors, and subordinates. In the natural sciences, for example, the competence of a research scientist is measured by proposal reviews, journal article reviews, numbers of graduate students desiring to work with the scientist, the placing of those students after their degrees, and so forth.

Competence is also an evolutionary thing. A number of people who were originally trained as physicists have become presidents of major universities. The competency requirements for a high level central administrator are not those of a research and teaching science faculty member. Hence, these people are now being assessed for competence in very different ways on very different dimensions. At a recent American

Physical Society meeting (January, 1976) several of these presidents alluded to the fact that they no longer thought of themselves as physicists.

Education cannot measure a student's continuing competence. All education can do is document that at certain times the student performed certain tasks to fulfill certain defined criteria. The difference is both philosophic and practical. Learning outcome statements become "did" statements instead of "will be able to" statements. The distinction also points out an important facet of much of education: the student learns to do something, not on the assumption that he or she will always be able to do that thing equally well on demand, but rather that the student, having understood that material once, will be much better able to relearn the material when that material is necessary in his or her life.

The Assessment of Attainments

Attainment statements should be couched in this "having performed" mode. The emphasis of attainments is, of course, proving "can do" by doing. Rules for writing and classifying attainment statements are those for writing objectives or competency statements. The instructional design team can often use the usual kinds of assessment choices. However, the use of attainment statements often forces additional kinds of assessment strategies to be considered. For example, if an attainment statement requires that a student explain the difference between the deterministic nature of classical mechanics and the probabalistic nature of quantum mechanics to a layman in such a way that the layman can demonstrate a certain kind of information and knowledge transferal, then the only proper assessment strategy is to have the student present such a discussion to at least one layman. Such a performance standard may, in fact, be an appropriate one for majors who wish to teach.

One final point before the paper turns to general and specific attainment statements for natural science majors. This paper will consistently draw a distinction

between terminal, general, or generic attainments, which must all be assessed directly and specific or enabling objectives, which may or may not be assessed. Whether or not an enabler is assessed is often more a function of the instructional pacing of the material than of anything else. The problem with much of present scientific instruction is that too much effort goes into the direct assessment of enablers (such as "The student wrote down the thin lens formula from memory"). Much too little time is then available for the assessment of generic or terminal attainments (such as "The student explained and diagrammed a complex lens system," which includes not only thin and thick lenses but also the focusing characteristics of the electron microscope and the TV tube). The learning map (or instructional task analysis tree) with its grouping and sequencing of events determines which attainments must be terminal and, hence, assessed. Other attainment statements can often be either terminal or enabling depending on how large a chunk of instruction must be given to the student without an assessment break. The distinction among various types of attainment statements or requirements will be helpful as the paper moves to discuss attainment requirements for natural science majors.

The Development and Assessment of Generic and Specific Attainment Requirements for Natural Science Majors

Figure 1 is a block diagram of the types of attainment requirements for majors in the natural sciences.

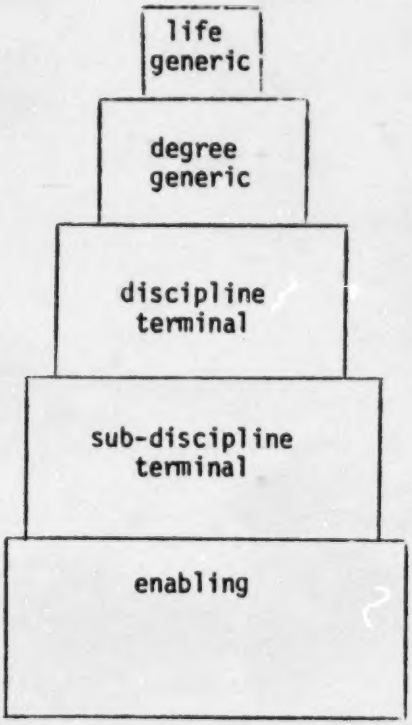
Schematic Drawing	Example Requirements
	Given a problem situation, the person automatically applies a problem-solving techniqu. Given a problem in an area studied, the student applies a problem-solving technique learned. Given a problem in physics, the student solved the problem as far as possible analytically. Given a mechanics problem, the student used F=ma or conservation laws to calculate the final situation. The student wrote down Newton's Second Law from memory. Given a 2nd order, total differential equation with constant coefficients, the student solved for the function.

FIGURE 1

The type of hierarchy shown in Figure 1 is typical of many natural science fields, and, in fact, of many disciplines beyond the natural sciences. There are always both enablers and a series of terminal level attainments. Many enablers have to do with the vocabulary of the field or the basic axioms and hypotheses. These enablers are usually internally generated and internally validated. That is, faculty involved with the project write the enablers and other faculty within the department review

and accept the results. Some empirical validation (quantifiable validation based on student achievement) comes from students' success reaching performance standards on terminal attainments. Enabling attainments are sometimes idiosyncratic to the major content faculty member most involved in the design; however, in the introductory and intermediate levels of the natural sciences, considerable consistency is found among sets of enablers. When enablers are assessed in the natural sciences, written or hardware mediated test instruments are practically always used.

The second level is sub-discipline attainment statements. All fields have major branches; each branch or sub-discipline has its own terminal outcomes. In physics, for example, sub-disciplines include mechanics, thermodynamics, statistical physics, solid state physics, electricity and magnetism, molecular physics, plasma physics, nuclear physics, high energy physics, and so forth. In traditional structures, post-secondary disciplines often delineate their course structures by sub-discipline.

The sub-discipline terminal attainment statements are usually internally generated and internally validated. There is sometimes a measure of external validation, that is, review and agreement on attainment statements by people working outside the department. In the case of sub-discipline attainments, external validation is performed by professionals in the field. There is some empirical validation of sub-discipline attainments by the success of students on discipline terminal attainments. The sub-discipline attainments are usually not particularly idiosyncratic. The assessment of these sub-discipline attainments are application oriented. Self-check, pre-assessment instruments are usually involved. Parts of the assessment strategies use written or hardware mediated devices. There is a tendency not to use human resources directly in the assessment (except as behind-the-scenes graders, when necessary). Greater use of jury examinations at this level is appropriate.

If, as often happens in the natural sciences, one stops at the level of sub-discipline attainment and does not consider the higher, more generic levels, the

resulting attainments become fractionated and do not often relate well one-to-another. For example, there may be little, if any, coherence between the attainments required in learning the mathematics of solid state statistical processes and those required in plasma physics. The delineation of the discipline terminal attainments serves to pull these fractionated, sub-discipline attainments together so as to have maximum cross-fertilization between the learning events for the various sub-disciplines. The issues considered in developing the discipline attainment statements tend to center around questions like: "What are the commonalities between mechanics and solid state physics?," or "How do the principles of electricity and magnetism relate to the attainments in plasma physics?." To some extent, these questions are really: "What should a physics major do, after he or she is all done with the sub-disciplines, to be awarded a physics major?" These discipline attainment requirements are both internally and externally generated; when departments sometimes involve non-university physicists in the development process for this level. The discipline terminal attainment statements are externally validated; empirical validation comes from employment of majors before or after graduation and by entrance to graduate schools. There is very little that is idiosyncratic about the discipline terminal attainments in those cases in which they have been developed. However, only a small number of situations have developed discipline terminal attainments, so the statistical validity of any general statement is suspect.

The assessment of discipline terminal attainments practically always involves both written (or hardware mediated) test instruments and jury examinations. The skills required tend to be very high cognitive levels, and examination by humans is used in one way or another. This is not surprising since those places using comprehensive examinations for their majors often include an oral examination in the final assessment. One is beginning to reach the level of "Does the student think and behave like a physicist?" The answers to such questions normally require human judgment.

The juries include representation from departments outside the student's major and minor. Validation of jury procedures is as difficult as for most jury processes such as masters and doctoral committee orals. The existence of attainment statements helps alot.

The degree generic attainments are those across-the-board attainment statements which identify and distinguish those with the degree from those without. A very few places have tried to develop these degree generic attainment statements. Few places have been completely successful. These attainment statements are more general skills and often clearly mix the affective with the cognitive domain. For example, to demand that someone automatically use a problem-solving technique is the operational means of determining that the person appreciates and feels comfortable with the processes of analysis, model-building, predictive comparison, formative evaluation, and so forth. For a liberal arts baccalaureate degree, one is almost trying to test how good the person feels about "intellectual pursuits." These high level attainments ought to be externally generated with internal advice, but they rarely are. The attainments at this level should be both internally and externally validated because the empirical validation is very difficult. Any empirical validation must come from effectiveness in later life. The degree generic attainments are usually more vague than one would like but, aside from their vagueness, there is relatively little that is idiosyncratic to the particular institution. These degree generic attainments are at such a high level that most of the assessment demands the use of human resources. One can conceive of a jury process, with very broad representation on the jury, which could be used for the assessment of these attainments. However, the author knows of no situation in which such adequate assessment techniques are used. Even in those places, which have listed degree gereric attainments, practice still comes dangerously close to assessing on lower level attainments and hoping that the final whole (the graduate) is greater than the sum of its parts.

As pointed out earlier, the final level, life generic competencies, cannot be the responsibility of the educational process. Furthermore, as is clear from the above discussion, those portions of the block diagram which are discipline dependent (and therefore classed as natural science per se) end at the discipline terminal attainment level. The rest of the structure must cut across discipline boundaries and be generic for the whole educational experience. At these upper levels, all disciplines meet and one begins to see the obvious commonalities among disciplines. As an example, Alverno College in Milwaukee has used a technique in which certain learning experiences and attainments in various disciplines give certain amounts of partial credit towards degree generic attainments. In such a system, the cross-fertilization of disciplines can become very clear.

Other Issues of Interest Along These Same Lines

There are several other issues related to the ones discussed above which warrant consideration. For example, what is the attainment structure (the block diagram) of natural science for the non-science major? The block diagram looks like Figure 2.

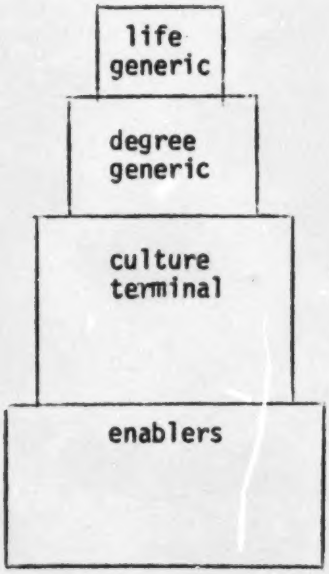
Schematic Drawing	Example Statements
	Given a problem situation, the person automatically applies a problem-solving technique. Given a problem in an area studied, the student applied a problem-solving technique learned. The student compared and contrasted Special Relativity and Classical Kinematics. The student compared the determinism of classical physics with the probabilistic view of quantum mechanics. The student identified the steps of a problem-solving technique. The student identified the steps in the experimental approach of science to the discovery of truth.

FIGURE 2

As is clear in the figure, the generic levels are much the same as those for the major. The differences in approach occur in the lower level of attainment. Structures like this one should guide the development of the material given to non-majors by natural science departments.

Another issue that deserves consideration is a detailed examination of the commonalities among discipline terminal attainment statements. Too few sets of such statements are well developed in the natural sciences to make extrapolation worth much. One hopes that as more sets are developed, someone will report on the common aspects which occur naturally. This empirical approach can then be complemented by standard a priori techniques with adequate validation.

What is the role of the natural sciences in the further development of the design structures and assessment techniques discussed here? The natural sciences are among the fields having the most sequential and most closely coordinated sub-disciplines. The natural sciences would be fertile ground for the development of the overall structure discussed above. The empirical/theoretical approach of the natural sciences is very closely allied to the approaches used in the development and implementation of systematically designed instruction. In many places, the natural sciences are among the forefront of educational innovation. If it became possible for natural scientists and educational technologists to work together on common problems, the natural science areas could become pivotal to the enumeration and implementation of the successful attainment structures post-secondary education badly needs.